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Low in-flight blood oxygen levels in CF CC-130 Aircrew

M.A. Paul
G.W. Gray

Defence R&D Canada
Technical Memorandum
DCIEM TM 2001-053
April 2001

National Defence Défense nationale

Canada

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Defence and Civil Institute of Environmental Medicine

Technical Memorandum
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Author

Michel A. Paul, M. Sc. and G.W. Gray, M.D. FRCP (C), Ph.D.

Approved by

Maj Zenon Myshkevich

Officer Commanding Aircrew Life Support Section

Approved for release by

K. M. Sutton

Chair, Document Review and Library Committee

Abstract

Introduction. Routine non-destructive testing (NDT) revealed cracks in a key aluminium airframe beam on E model CC130. Consequently, the CF Aeronautical Engineering community issued an operational restriction to all squadrons flying these aircraft that cabin pressure differentials were to be maintained a no more than 10psi (pounds per square inch). At service ceilings ranging from 24,000 ft to 28,000 ft, a 10psi cabin pressure differential produces corresponding cabin altitudes ranging from 8,000 ft to 10,000 ft. Such cabin altitudes have been implicated in 2 recent physiological incidents. Of the 20 CC130 aircraft based at 8 Wing (CFB Trenton), 17 are the affected E models. The 8 Wing Surgeon requested that DCIEM monitor percent arterial oxyhemoglobin saturation (% SaO_2) with a view to quantification of this aero-medical problem and possible countermeasures to protect the crews flying these aircraft.

Methods. A DCIEM scientist accompanied an augmented 9-man crew on a routine re-supply mission from 8 Wing to Zagreb and return. During this mission, SaO_2 readings (at ground level, 8,000 ft and 9,000 ft) were obtained from all 9 crewmembers, as well as the DCIEM scientist.

Results & Discussion. Cabin altitudes during transatlantic flight reached 8,000 ft ASL on the outbound leg and 9,000 ft ASL on the return leg. Mean SaO_2 readings were 97.0 ± 0.94, 90.06 ± 0.34, and 87.11 ± 0.55 for ground level, 8,000 ft, and 9,000 ft respectively. Such SaO_2 levels are a normal physiologic response to these altitudes, and indicate a mild hypoxia which can produce symptoms of acute mountain sickness such as head-ache, gastro-intestinal discomfort, and abnormal levels of fatigue. However, the crews are already stressed with documented sleep hygiene problems and corresponding fatigue-induced impact on psychomotor performance. The additional stress of mild hypoxia to these existing stressors is worrisome.

Conclusions. Limiting the pressure differential to 10psi in CC130 transatlantic operations results in cabin altitudes as high as 10,000 ft. At these cabin altitudes, this study confirms that crewmembers develop mild hypoxia. With multiple stressors already inherent in the long-range strategic role, the additional stress of mild hypoxia creates an unfavourable environment which is a potential flight safety risk.

Recommendations. The crews should be provided with supplementary oxygen. Because the normal on-board oxygen is a limited supply of LOX (liquid oxygen) and is intended for emergency purposes, another oxygen system must be found. Further, the on-board oxygen delivery system is via uncomfortable oro-nasal masks and associated mask suspension system. These masks impact on crew communication/coordination and the antiquated suspension system does not easily interface with the headsets and is painful to tolerate for long periods of time. An alternative could be a low-flow pulse-dose system. Several such systems are on the market and it is recommended that DCIEM ALS (Aircrew Life Support) Section be tasked to identify the best such system for possible purchase in support of long-range CC130 air transport aircrew.

Résumé

Introduction. Des essais non destructifs (END) de routine ont révélé des fissures dans une poutre clé en aluminium de la cellule d'un CC130, modèle E. Par conséquent, la communauté du génie aéronautique des FC a publié une restriction opérationnelle à tous les escadrons exploitant ces appareils pour qu'ils maintiennent la pression différentielle dans la cabine à au plus 10 lb/po^2. Aux plafonds pratiques compris entre 24 000 et 28 000 pieds, une pression différentielle en cabine de 10 lb/po^2 se traduit par des altitudes cabine correspondantes comprises entre 8 000 et 10 000 pi. Ces altitudes cabine ont été mêlées à deux (2) récents incidents physiologiques (décembre 2000 et février 2001). Des 20 appareils CC130 basés à la 8^e Escadre (BFC Trenton), 17 sont les modèles E visés. Le médecin-chef de l'escadre a demandé à l'IMED de contrôler le pourcentage de saturation du sang artériel en oxygène (% SaO_2) afin de quantifier ce problème aéromédical et de prendre des contre-mesures possibles pour protéger le personnel navigant volant à bord de ces appareils.

Méthodes .Un chercheur de l'IMED a accompagné un équipage augmenté de 9 personnes lors d'une mission aller-retour de réapprovisionnement de routine, de la 8^e Escadre jusqu'à Zagreb. Au cours de la mission, les lectures de SaO_2 (au niveau du sol, à 8 000 pi et à 9 000 pi) ont été obtenues des neuf membres d'équipage ainsi que du chercheur de l'IMED.

Résultats et constatations. Les altitudes cabine pendant le vol transatlantique ont atteint 8 000 pi ASL sur l'étape à l'aller, et 9 000 pi ASL sur l'étape de retour. Les lectures SaO_2 moyennes ont été de $97{,}0 \pm 0{,}94$, de $90{,}06 \pm 0{,}34$ et de $87{,}11 \pm 0{,}55$ au niveau du sol, à 8 000 pi et à 9 000 pi respectivement. Ces niveaux SaO_2 constituent une réaction physiologique normale à ces altitudes et elles dénotent une légère hypoxie qui peut produire les symptômes d'un mal des montagnes aigu, comme des maux de tête, des malaises gastro-intestinaux et un fatigue anormale. Par contre, les équipages sont déjà sujets à des troubles du sommeil qui sont documentés et aux conséquences correspondantes induites par la fatigue sur leur comportement psychomoteur. Le stress posé par cette légère hypoxie s'ajoute aux agents stressants existants et il est inquiétant.

Conclusions. Le fait de limiter la différence de pression à 10 lb/po^2 lors des vols transatlantiques de CC130 se traduit par des altitudes cabine pouvant atteindre 10 000 pi. À ces altitudes cabine, l'étude confirme que les membres d'équipage sont victimes d'une légère hypoxie. En raison des agents stressants multiples déjà présents dans les missions stratégiques à long rayon d'action, le stress additionnel d'une légère hypoxie crée un environnement défavorable qui pourrait compromettre la sécurité des vols.

Recommandations. Les équipages devraient bénéficier d'oxygène supplémentaire. Comme l'oxygène se trouvant normalement à bord est une quantité réduite d'oxygène liquide (LOX) destinée à être utilisée en cas d'urgence, il faut recourir à un autre système d'oxygène. De plus, l'alimentation en oxygène à bord se fait au moyen d'un masque peu confortable qui recouvrent le nez et la bouche et qui est équipé d'un système de suspension connexe. Ce masque gêne la coordination et la communication entre les membres d'équipage, et le système de suspension désuet gêne le casque d'écoute et est douloureux à endurer pendant de longues périodes. On pourrait choisir a la place un système d'oxygène à doses pulsées et à

faible débit. Plusieurs circuits de ce type sont sur le marché, et il est recommandé que la Section des systèmes de vie de l'équipage (ALS) de l'IMED soit chargée de trouver le meilleur système pour qu'il soit acheté à l'intention du personnel navigant de l'avion de transport CC130 à long rayon d'action.

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Executive summary

During routine non-destructive testing (NTD) key aluminium airframe beams on E model CC130 aircraft were cracked. In response, the CF Aeronautical Engineering community issued an operational restriction to all squadrons flying these E model CC130 aircraft to maintain a cabin pressure differential (relative to aircraft altitude) of no more than 10psi (pounds per square inch). The consequence of a 10psi cabin pressure differential is higher cabin altitude. At service ceilings between 24,000 and 28,000 ft cabin altitudes range from 8,000 to 10,000 ft. Such cabin altitudes have been implicated in two recent physiological incidents (December 2000, and February 2001). Of the 20 CC130 aircraft based at 8 Wing (CFB Trenton), 17 are the affected E models. The 8 Wing Surgeon requested assistance from DCIEM with a view to quantification of this aero-medical problem and possible countermeasures to protect the crews flying these aircraft.

A DCIEM scientist accompanied an augmented 9-man crew on a routine re-supply mission from 8 Wing to Zagreb and return. During this mission, SaO_2 readings (at Ground Level, 8,000 ft and 9,000 ft) were obtained from all 9 crewmembers, as well as the DCIEM scientist.

Cabin altitudes during transatlantic flight reached 8,000 feet ASL on the outbound leg and 9,000 feet ASL on the return leg. The mean SaO_2 readings ranged from 97% at ground level to 87% at 9,000 ft. Such SaO_2 levels are a normal physiologic response to these altitudes, and indicate a mild hypoxia, which can produce symptoms of acute mountain sickness such as headache, gastro-intestinal discomfort, and abnormal levels of fatigue. However, the crews are already stressed with documented sleep hygiene problems and corresponding fatigue-induced impact on psychomotor performance. The addition of mild hypoxia to these existing stressors is worrisome.

Limiting the pressure differential to 10psi in CC-130 transatlantic operations results in cabin pressures up to 10,000 feet. At these cabin altitudes, this study confirms that crewmembers develop mild hypoxia. With multiple stressors already inherent in the long-range strategic role, the additional stress of mild hypoxia creates an unfavourable environment which is a potential flight safety risk.

The crews should be provided with supplementary oxygen. Because the on-board oxygen is a limited supply of LOX (liquid oxygen) and is intended for emergency purposes, another oxygen system must be found Further, the on-board oxygen delivery system is via uncomfortable oro-nasal masks and associated mask suspension system. These masks impact on crew communication/coordination and the antiquated suspension system does not easily interface with the headsets and is painful to tolerate for long periods of time. An alternative could be a low-flow pulse-dose system. Several such systems are on the market and it is recommended that DCIEM ALS (Aircrew Life Support) Section be tasked to identify the best such system for possible purchase in support of long-range CC130 air transport aircrew.

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Sommaire

Des essais non destructifs (END) de routine ont révélé des fissures dans des poutres clé en aluminium de la cellule sur un CC130, modèle E. Par conséquent, la communauté du génie aéronautique des FC a publié une restriction opérationnelle à tous les escadrons exploitant ces appareils pour qu'ils maintiennent la pression différentielle dans la cabine à au plus 10 lb/po^2. La conséquence d'une pression différentielle en cabine de 10 lb/po^2 est une altitude cabine supérieure. Aux plafonds pratiques compris entre 24 000 et 28 000 pieds, une pression différentielle en cabine de 10 lb/po^2 se traduit par des altitudes cabine correspondantes comprises entre 8 000 et 10 000 pi. Ces altitudes cabine ont été mêlées à deux (2) récents incidents physiologiques (décembre 2000 et février 2001). Des 20 appareils CC130 basés à la 8^e Escadre (BFC Trenton), 17 sont les modèles E visés. Le médecin-chef de l'escadre a demandé l'aide de l'IMED pour qu'il quantifie ce problème aéromédical et qu'il suggère des contre-mesures possibles pour protéger le personnel navigant volant à bord de ces appareils.

Un chercheur de l'IMED a accompagné un équipage augmenté de 9 personnes lors d'une mission aller-retour de réapprovisionnement de routine, de la 8^e Escadre jusqu'à Zagreb. Au cours de la mission, les lectures de SaO_2 (au niveau du sol, à 8 000 pi et à 9 000 pi) ont été obtenues des neuf membres d'équipage ainsi que du chercheur de l'IMED.

Les altitudes cabine pendant le vol transatlantique ont atteint 8 000 pi ASL sur l'étape à l'aller, et 9 000 pi ASL sur l'étape de retour. Les lectures SaO_2 moyennes s'échelonnaient entre 97 % au niveau du sol et 87 % à 9 000 pi. Ces niveaux SaO_2 constituent une réaction physiologique normale à ces altitudes et elles dénotent une légère hypoxie qui peut produire les symptômes d'un mal des montagnes aigu, comme des maux de tête, des malaises gastro-intestinaux et un fatigue anormale. Par contre, les équipages sont déjà sujets à des troubles du sommeil qui sont documentés et aux conséquences correspondantes induites par la fatigue sur leur comportement psychomoteur. Le stress additionnel posé par cette légère hypoxie aux agents stressants existants est inquiétant.

Le fait de limiter la différence de pression à 10 lb/po^2 lors des vols transatlantiques de CC130 se traduit par des altitudes cabine pouvant atteindre 10 000 pi. À ces altitudes cabine, l'étude confirme que les membres d'équipage sont victimes d'une légère hypoxie. En raison des agents stressants multiples déjà présents dans les missions stratégiques à long rayon d'action, le stress additionnel d'une légère hypoxie crée un environnement défavorable qui pourrait compromettre la sécurité des vols.

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de l'équipage (ALS) de l'IMED soit chargée de trouver le meilleur système pour qu'il soit acheté à l'intention du personnel navigant de l'avion de transport CC130 à long rayon d'action.

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Introduction

Routine NDT (non-destructive testing) on CF CC130 fleet has revealed cracks in a certain airframe beam in 17 of the 20 E models based at 8 Wing. The response from the CF (Canadian Forces) Aerospace Engineering community has been to issue an operational restriction (1) which directs crews flying these aircraft to limit the pressure differential (cabin pressure relative to aircraft altitude) to 10psi (pounds per square inch). Prior to this restriction, these aircraft could maintain a 15.4psi cabin pressure differential. The consequence of the 10psi differential is a cabin altitude ranging from 8,000 ft to 10,000 ft ASL (above sea level) while the aircraft is at operational altitudes of 24,000 ft to 28,000 ft. The 15.4psi pressure differential would have put cabin altitude between 1,500 ft and 2,000 ft at those operational altitudes. The recently elevated cabin altitudes have been implicated in 2 recent physiological incidents (3, 9). Consequently, the 8 Wing Flight Surgeon Office asked DCIEM to conduct blood oxygen measurements on aircrew during a transatlantic re-supply mission (2).

Methods

The mission call sign/mission number was 4266. The augmented crew amounted to 9 personnel (3 pilots, 2 navigators, 2 flight engineers, and 2 loadmasters) plus the DCIEM scientist for a total of 10 crewmembers. All 10 crewmembers were monitored for SaO_2 (arterial oxyhemoglobin saturation) at ground level before the mission and at several cabin altitudes during the mission. The SaO_2 readings were performed with a handheld pulse oxymeter manufactured by Nellcor Puritan Bennett of Pleasanton, California (model NP 40).

Results and discussion

Figure 1 is a plot of cabin altitude against aircraft altitude for the mission aircraft. Figure 2 is a plot depicting percent SaO_2 (mean values ± s.e.m.) against cabin altitude. Because the aircraft was committed to reach TOC (top of climb) as expediently as possible after take-off, there was no opportunity to monitor SaO_2 during the actual climb-out.

Cabin altitudes during transatlantic flight reached 8,000 feet ASL during the outbound leg and 9,000 feet ASL during the return leg. Mean SaO_2 readings were 97.0 ± 0.94, 90 06 ± 0.34, and 87.11 ± 0.55 for ground level, 8,000 ft, and 9,000 ft respectively.

Figure 3 illustrates SaO_2 readings on one individual on the return transatlantic leg which was conducted at 26,000 ft with a corresponding cabin altitude of 9,000 ft. Prior to a 2-minute pure oxygen breathing session this subject had an SaO_2 of 85%. Within 30 seconds of starting to breathe oxygen via the on-board emergency oxygen system, SaO_2 went from 85% to 97 %, and by 45 seconds reached 100%. This subject stayed on oxygen for exactly 2 minutes (Figure 3). SaO_2 dropped to 92% within 4 minutes of having ceased breathing oxygen. Over the subsequent hour his SaO_2 fell to 90%. The SaO_2 levels over the next several hours were limited to 88%-89%, or 4% to 5% higher than the pre-oxygen SaO_2 levels. That SaO_2

remained 4% to 5% higher for several hours, relative to pre-oxygen breathing, is probably not due to having breathed oxygen for 2 minutes. However, one possible explanation for this slightly elevated SaO_2 is a baroreceptor-mediated increase in ventilatory drive which would indicate an acute adaptation to this level of cabin altitude. These data show that by ground level clinical standards, these aircrew have low blood oxygen levels at the cabin altitudes of this mission.

The effect of mild hypoxia on performance has been the subject of considerable research. Some studies reported that psychomotor performance was impaired at 8,000 ft (4, 8, 10), and one study reported impaired performance as low as 5,000 ft (6). However, these findings were not confirmed in other studies (5, 7, 12). These discrepancies regarding the effects of mild hypoxia on perceptual-motor performance could have been due to several factors. The main ones are as follows: (i) the range of performance tests used may have different sensitivities to hypoxia; (ii) the way hypoxia is induced (hypobaric or low oxygen mixtures at ground level) may not result in equivalent hypoxia; (iii) and the physical workload of the test subjects while their performance is being assessed could have an effect on the ultimate severity of hypoxia.

Figure 4 shows data from an earlier study involving 144 subjects in the DCIEM altitude chamber (12). In this study, half of the subjects performed very mild exercise in order to duplicate the 600 ml VO_2 (oxygen uptake) which corresponds to the workload in a normal cockpit environment (11). This approximate doubling of resting VO_2 causes a further decrease in SaO_2 at 10,000 ft and at 12,000 ft (Figure 4). This suggests that for cabin altitudes approaching 10,000 ft, physically active CC130 aircrew could experience further transient decreases in SaO_2 levels relative to resting aircrew. In fact, 2 crewmembers complained of laboured breathing in response to the 'workload' of leaving the cockpit in order to use the toilet at the back of the aircraft. Their laboured breathing dissipated within 5 to 10 minutes of returning to their cockpit positions. The study scientist who had previous experience on these missions when the Cabin altitudes were around 1,500 ft, found that the current cabin altitudes induced a feeling of unexpected fatigue and significant abdominal distress due to altitude-induced abdominal gas expansion. The Paul and Fraser study (12) also found that the ability to learn new tasks was not impaired at altitudes up to 12,000 ft. However, this was an acute hypoxia exposure for only 2 hours and is not comparable to the more prolonged exposures occurring during long-range CC130 air transport operations which can involve exposure to mild hypoxia for 12 to 14 hours.

Conclusion

While limiting the CC130E cabin pressure differential to 10psi is an operational necessity, the resultant cabin altitudes of up to 10,000 feet ASL on long strategic missions will cause mild to moderate hypoxia in crewmembers. Previous studies on long-haul strategic missions have demonstrated problems with crew rest and sleep hygiene, and fatigue-related effects on psychomotor performance (13) The added stress of hypoxia may cause further fatigue and performance decrement, with a potential compromise of flight safety. Provision of a suitable

comfortable oxygen system for crews operating at these high cabin altitudes is an urgent operational priority.

Recommendations

Given the hypoxia at operational cabin altitudes demonstrated in this pilot study and the potential confounding effect on other known stressors of fatigue and sleep hygiene issues, it is recommended that long-range airlift CC130 crews be supplied with supplemental oxygen to use throughout the flight. The current on-board oxygen system is for emergency purposes and is uncomfortable to wear for extended periods of time, interferes with communication, and is unsuitable for extended oxygen delivery. A suitable alternative system should be defined for this particular use. Such a system could be a low-flow pulse-dose demand system delivering supplemental oxygen through a comfortable nasal cannula. These systems are commercially available and DCIEM could be tasked to define the most appropriate and cost-effective system.

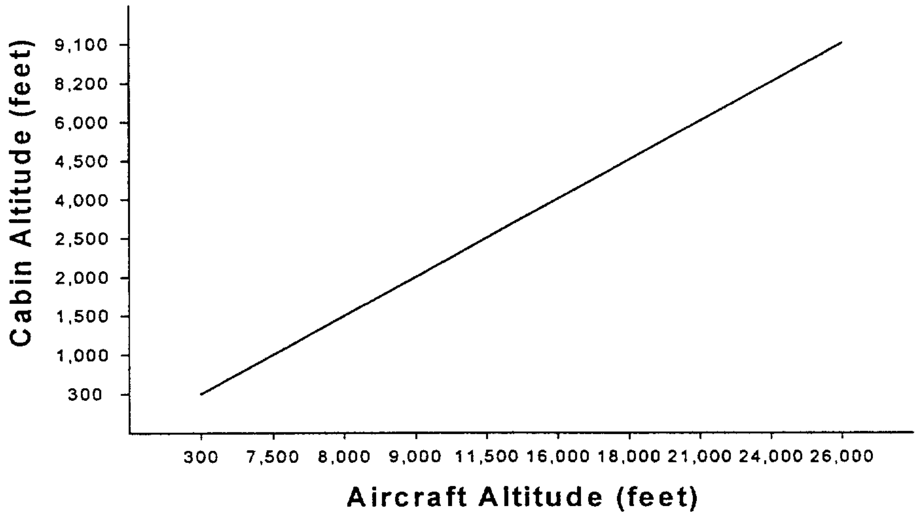

Figure 1. Cabin vs Aircraft Altitude from ground level to operational ceiling while maintaining 10psi cabin pressure differential.

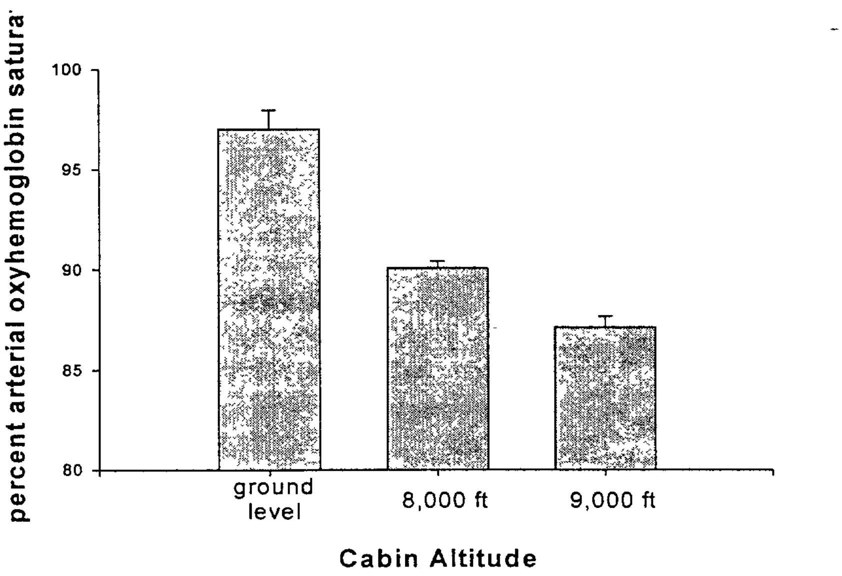

Figure 2 Arterial oxyhemoglobin saturation (mean ± s e.m.) vs ground level and cabin altitude representing data from 10 subjects Ground level was field elevation at CFB Trenton (280 ft a s l.).

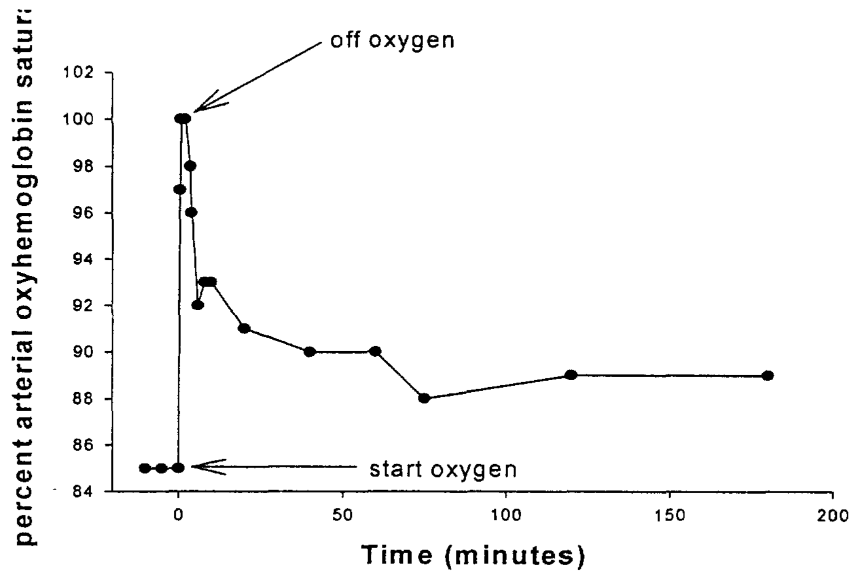

Figure 3. SaO_2 in one subject at 9,000 ft cabin altitude before, during, and after oxygen breathing

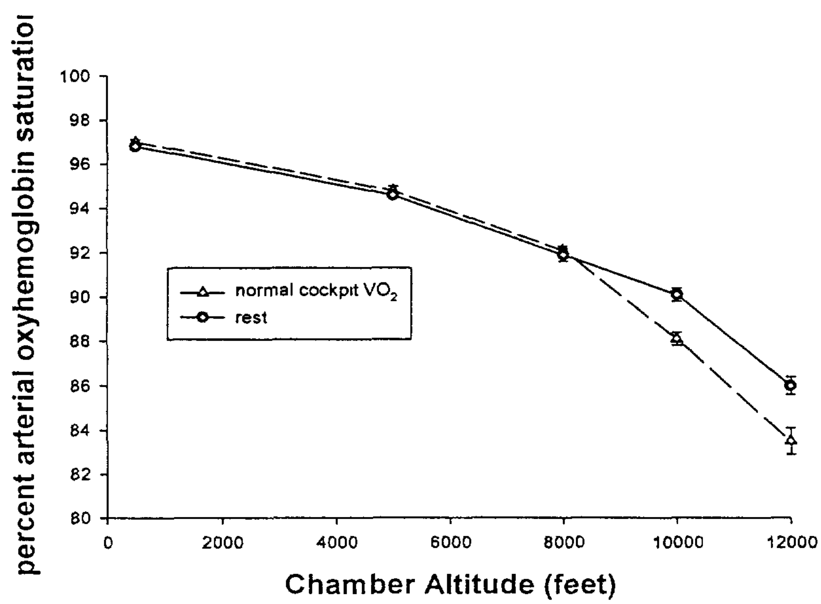

Figure 4. mean arterial oyxhemoglobin saturation ± s.e.m. across altitudes with subjects at rest or at normal cockpit VO_2

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14. ABSTRACT

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Conclusions. Limiting the pressure differential to 10psi in CC130 transatlantic operations results in cabin altitudes as high as 10,000 ft. At these cabin altitudes, this study confirms that crewmembers develop mild hypoxia. With multiple stressors already inherent in the long-range strategic role, the additional stress of mild hypoxia creates an unfavourable environment which is a potential flight safety risk.

Recommendations. The crews should be provided with supplementary oxygen. Because the normal on-board oxygen is a limited supply of LOX (liquid oxygen) and is intended for emergency purposes, another oxygen system must be found. Further, the on-board oxygen delivery system is via uncomfortable oro-nasal masks and associated mask suspension system. These masks impact on crew communication/coordination and the antiquated suspension system does not easily interface with the headsets and is painful to tolerate for long periods of time. An alternative could be a low-flow pulse-dose system. Several such systems are on the market and it is recommended that DCIEM ALS (Aircrew Life Support) Section be tasked to identify the best such system for possible purchase in support of long-range CC130 air transport aircrew.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

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